Landsat 7 Science Data Processing: A Systems Overview

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ABSTRACT

The Landsat 7 Science Data Processing System, developed by NASA for the Landsat 7 Project, provides the science data handling infrastructure used at the Earth Resources Observation Systems (EROS) Data Center (EDC) Landsat Data Handling Facility (DHF) of the United States Department of Interior, United States Geological Survey (USGS) located in Sioux Falls, South Dakota. This paper presents an overview of the Landsat 7 Science Data Processing System and details of the design, architecture, concept of operation, and management aspects of systems used in the processing of the Landsat 7 Science Data.

Keywords: Landsat 7, Data Processing, Science Data Processing, Geometric Processing, Radiometric Processing, Freeware

1. INTRODUCTION

The Landsat 7 (L7) Science Data Processing System consists of the following processing systems: Landsat Ground Station (LGS), Landsat Processing System (LPS), Image Assessment System (IAS), Level 1 Product Generation System (LPGS), Level 1 Product Distribution System (LPDS) and the EROS Data Center (EDC) Distributed Active Archive Center (DAAC) Earth Observing System (EOS) Data and Information System (EOSDIS) Core System (ECS). The LGS tracks the satellite and acquires the downlink signal for real-time transfer to the LPS. It also receives playback tapes from the EOS Polar Ground Network (EPGN). The LPS captures raw wideband data, performs Level Zero processing, generates image, metadata and browse files, and stages the data for subsequent transfer to the ECS. The IAS enables the L7 Science Office and Mission Management Office to perform radiometric and geometric characterizations and quality assessments of the data. These characterizations are used in the generation of the Calibration Parameter File (CPF). The ECS facilitates long-term data archiving; science data search, browse, and order; and Level Zero Reformatted (L0R) data distribution. The LPGS and LPDS work together with the ECS to facilitate on-demand Level 1 product generation, packaging, and distribution. Figure 1 illustrates the interconnections of the systems. This paper gives an overview of each of the systems as well as specific details about the LPS, IAS, LPDS, and LPGS hardware and software architectures and management aspects of the systems development.

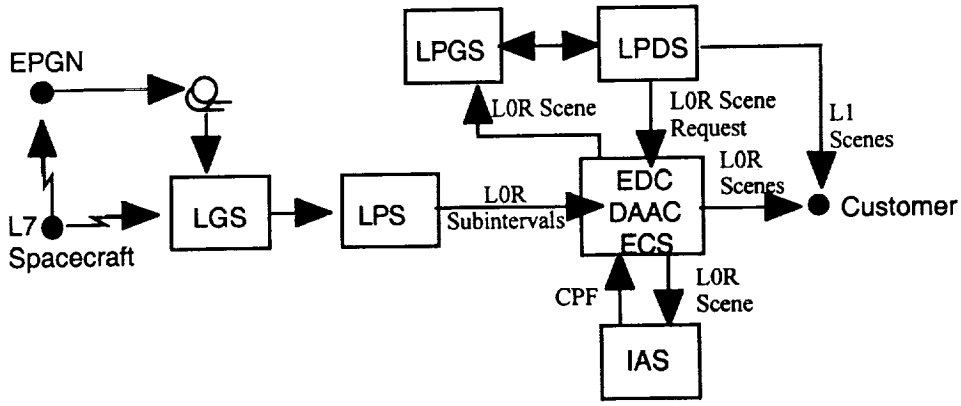

Figure 1. Landsat 7 Science Data Processing Block Diagram

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2. OVERVIEW - LANDSAT GROUND STATION (LGS)

The Landsat Ground Station (LGS) is responsible for acquiring the Enhanced Thematic Mapper Plus (ETM+) X-Band signal from the Landsat 7 spacecraft via any two of the three possible 150-Mbps X-band downlinks. The LGS equipment receives and demodulates each X-band downlink into two 75-Mbps I and Q channels and forwards the data to the LPS. Additionally, the LGS can receive and transmit S-Band telemetry and generate two-way Doppler tracking for each pass. The LGS interfaces with the Mission Operations Center (MOC) for receipt of spacecraft contact schedules and orbital elements, exchange of spacecraft commands and telemetry data, transmission of Doppler tracking data, and forwarding of post pass and equipment status reports.

The LGS antenna system consists of a single 10-meter, S- and X-Band, AZ/EL/Tilt Pedestal antenna, a boresight collimation source, and redundant Low-Noise Amplifiers by Datron. Additionally, it has a 200W S-Band transmitter by Microdyne. The LGS also utilizes X-Band downconverters, demodulators and bit synchronizers, built by Scientific Atlanta, a PC-based Monitor and Control System integrated with FactoryLink COTS software by USDATA Corp., a matrix switch by Matrix Switch, and four DIS 160I recorders by Ampex. [Ω]

The LGS was designed for minimal operations intervention. Its Monitor and Control System automatically receives spacecraft contact and ephemeris information from the MOC for autonomous station configuration and pass acquisition. During a spacecraft pass the X-band signal is downlinked, demodulated, bit synchronized, and forwarded to the LPS in real-time for raw data capture. The LGS operator, performs pass coordination with the MOC, trouble shoots system anomalies, supports systems contingency procedures, and performs routine system maintenance. Additionally, the LGS operator schedules and loads tapes from the EPGN for data playback from the Ampex recorders to the LGS for subsequent capture and processing by the LPS.

3. OVERVIEW - LANDSAT PROCESSING SYSTEM (LPS)

The Landsat Processing System (LPS) is responsible for raw ETM+ science data capture, Level 0R processing, imagery generation, and the subsequent transfer of all imagery to the ECS for long-term archiving and distribution. The LPS was designed to capture and process the equivalent of 275 scenes (i.e., 140 GB) of science data per day with no more than a 16-hour latency from data acquisition to L0R processing completion.

The major functions of the LPS are summarized as follows:

- Capture Raw ETM+ science data in real-time at 75-Mbps directly to disk
- Synchronize Major Frames and perform error detection and correction[1]
- Identify subintervals, scenes and scan line offsets
- Generate bands (1-6L, 6H-8), metadata, and browse files
- Perform Cloud Cover Assessment and Scene Quality scoring
- Interface with the ECS for L0R subinterval data transfer and ingest
- Produce real-time moving window display during processing
- Facilitate systems operations, status monitoring, configuration, activity scheduling, and management

3.1 Hardware Architecture

The operational LPS hardware consists of five Silicon Graphics, Inc. (SGI) Challenge XL computers, two Indy workstations, and two X-terminals. Each SGI Challenge XL is configured with eight CPUs, 512 MB of RAM, a VME interface module, a custom built VME-9U-VSIO[τ] high-speed serial interface board, approximately 178 GB of Ciprico RAID external disk drives, a DLT 4000 library, and a DLT 7000 tape drive. Four of the five SGI systems are required for nominal operations including raw ETM+ data recording, science data processing, and data transfer. The fifth system is a "warm-spare" supporting activities such as training, software maintenance, and testing. The Indy workstations and X-terminals are used as operational terminals supporting the LPS graphical user interfaces and the moving window displays. The custom built VME-9U-VSIO high-speed serial interface board, inserted into each SGI XL VME backplane, accepts as input the 75-Mbps serial differential

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[Ω] Note: A valuable tool used to validate the raw ETM+ stream was the DataScope by Jackson and Tull, Seabrook, Md.

[τ] Note: The VME-9U-VSIO card was built by General Standards Corporation, Huntsville, Alabama

Emitter Coupled Logic (ECL) clock and data signals from the LGS. A SGI developed custom device driver interfaces the VME-9U-VSIO card to the SGI IRIX operating system.

3.2 Software Architecture

The software component of the LPS consists of an Oracle database and seven software subsystems. The seven subsystems are Raw Data Capture, Raw Data Processing, Major Frame Processing, Payload Correction Data Processing, Image Data Processing, Data Transfer, and Process Management and Control. All inter process communication takes place via shared memory or an Oracle database. The user interface is based on Oracle Forms and Menus.

- The Raw Data Capture Subsystem is responsible for capturing raw ETM+ wideband data in real-time to a file for subsequent processing. It generates a raw data file of unsynchronized Consultative Committee for Space Data Systems (CCSDS) major frames and an ASCII metadata file with contact period information in addition to the generation of a data record in the database. The raw data capture process interfaces with a custom device driver developed by SGI that performs direct memory accessing for data ingest and transfer.

- The Raw Data Processing Subsystem accepts the raw data file from the raw data capture subsystem, performs frame synchronization, annotates the channel access data units, performs error detection and correction, generates data quality and accounting statistics, and transfers the data to the major frame processing subsystem

- The Major Frame Processing Subsystem is responsible for identifying a major frame, filling missing frames, determining major frame time and the subinterval, deriving band data offsets, generating the calibration and mirror scan correction data files, extracting the virtual channel data unit status information, extracting payload correction bytes, and generating the quality and accounting data

- The Payload Correction Data Processing Subsystem is responsible for generating the payload correction file, identifying each scene in accordance with the Worldwide Reference System (WRS) on a subinterval basis, and determining the Sun azimuth / elevation, horizontal display shift, and calibration door activity for each scene.

- The Image Data Processing Subsystem is responsible for generating the nine Landsat 7 band files (B1-6L, 6H-8), a browse image, the moving window display for operations, a cloud coverage assessment score, and accounting information that is inserted into the metadata files.

- The Data Transfer Subsystem interfaces with the ECS. It notifies the ECS of data availability, receives the data transfer acknowledgements and deletes data after successful transfer

- The Process Management and Control Subsystem is responsible for all system-level control and monitoring of the LPS devices and processes and provides the interface between the LPS and the operator. It facilitates updating the LPS processing parameters and thresholds, contact schedules, and automatic or manual execution of system tasks such as raw data capture and Level Zero processing.

3.3 Concept of Operations

An operator configures four of the five LPS computers with a daily contact schedule received from the MOC via the shared Oracle database. From this schedule, operational computers automatically perform data capture, processing, and transfer functions. The operator views gross image quality and the progress of the data Level Zero processing with the dynamically updated moving window display.

The nominal data processing flow is as follows: during either real-time contact with the satellite or tape playback the LPS SGI systems record the raw bit stream directly to RAID disk. After the raw data capture event is complete, the LPS initiates Level Zero and Image Processing for L0R subinterval generation. Upon completion of the processing a data-availability-notice is sent to the ECS for data transfer scheduling. When the ECS is ready, it ingests the L0R data subintervals and acknowledges data transfer status to the LPS. In support of potential reprocessing requests each operational LPS SGI makes a short-term copy of the raw data with the DLT 4000 tape library.

3.4 Management Aspects

The LPS project began in June of 1994. It was designed, developed, tested and deployed over a period of approximately 5 years including the last 18 months of maintenance. The LPS software is sized at approximately 100,000 lines of Deliverable Source Instructions (DSI) including C code, header files, and Oracle Forms and Menus. The most significant issue that permeated every facet of the LPS development was the lack of good prelaunch data from the Landsat 7 instrument. As the result of no prelaunch data non-trivial format discrepancies, e.g., extra 0 byte, resulted in significant software changes at a time when development staff profiles were shrinking to maintenance levels. Additionally, some of the LPS capabilities, e.g., cloud cover assessment or WRS accuracy, could not be validated until the spacecraft was on nominal orbit. This necessitated the retention of highly skilled software maintenance personnel, which was incongruent to the staffing budgets. The success of the LPS project is attributed to the patience and thorough testing by operations personnel, industrious and responsiveness of the development personnel, and highly dedicated engineering and development team members.

4. OVERVIEW - IMAGE ASSESSMENT SYSTEM (IAS)

The Image Assessment System (IAS) is responsible for image quality assessment and instrument calibration[2]. In assessing image quality, IAS monitors and calibrates the radiometric and geometric performance of the ETM+ sensors. The calibration parameters are stored in a Calibration Parameter File (CPF) that is subsequently bundled with the L0R products and distributed by the ECS. Up to 10 L0R images are retrieved from the ECS each day and processed by the IAS to Level 1 radiometrically corrected (L1R) and Level 1 geometrically corrected (L1G) format. The IAS provides the tools needed by the Landsat Mission Management Office to analyze and manage instrument or data format anomalies.

The major functions of the IAS are summarized as follows:

- Assess Landsat 7 image quality to ensure compliance with the radiometric and geometric requirements of the spacecraft and the ETM+ sensor
- Generate Level 1 products that are radiometrically and geometrically corrected
- Compensate for inoperable and saturated detectors, and image artifacts of striping, banding, coherent noise, memory effect, scan correlated shift, and dropped scan lines
- Produce geometric products that have been systematically corrected, precision corrected, and terrain corrected
- Produce ETM+ calibration information using Internal Calibrator (IC), Partial-Aperture Solar Calibrator (PASC), and Full-Aperture Solar Calibrator (FASC), and night scene data
- Generate and archive ETM+ trending data for long-term analysis
- Produce radiometric and geometric calibration updates to the CPF

4.1 Hardware Architecture

The operational IAS hardware consists of one SGI Origin 2000 computer and three SGI O2 workstations. The Origin 2000 contains four R10K CPUs, two GB of RAM, and has 288 GBs of Ciprico RAID disk drives attached. The O2 workstations are each equipped with a four GB disk drive, 512MB RAM, and monitors with a 1280x1024 resolution. The Origin 2000 performs all of the processing, and the O2 workstations perform data and image analysis, anomaly investigation, and report generation activities. One of O2 workstations was designed to serve as a system console for the Origin 2000.

4.2 Software Architecture

The IAS software architecture incorporates custom C programming language and several commercial-off-the-shelf (COTS) products. The architecture was designed to minimize IAS software development time. The COTS products include the Oracle Database Management System, Environment for Visualizing Images (ENVI), and Interactive Data Language (IDL). All inter-process communication occurs via the Oracle database or shared memory. The operator user interface is provided through Oracle Forms and the analyst user interface is provided through ENVI and IDL. Hierarchical Data Format (HDF) tools and Application Programming Interfaces (API) are used to read and write the L0R scenes received from the EDC. Adobe FrameMaker is used for producing IAS reports. The IAS software consists of the following subsystems: Process Control, Data Management, Radiometric Processing, Geometric Processing, and Evaluation and Analysis.

- The Process Control Subsystem provides capabilities for planning, monitoring, and controlling work orders. It permits the operator to set up work orders specifying the processing to be performed on the data, to prioritize

the processing to be performed, and to monitor the status of the work order execution. Process Control performs automated work order execution by monitoring required and available system resources, initiating application processing, and monitoring application execution status. It controls the execution of radiometric and geometric processing by initiating and managing the Level 1 processing.

- The Data Management Subsystem ingests, archives, and distributes the IAS data. The data consist of image data, ancillary data, characterization and calibration results, and reports. Data Management transfers data during ingest using File Transfer Protocol (FTP) functions, stores data in the appropriate internal data stores, updates data availability information, and manages disk resources. For data export, Data Management performs the appropriate data formatting and supports the FTP transmission of these data to external systems. The Data Management software also performs quality checking and L0R correction upon receipt of the data from the ECS. It prepares data at the start of image processing by correcting the data based on the payload correction data (PCD) and the mirror scan correction data (MSCD).

- The Radiometric Processing Subsystem performs radiometric calibration and L1R processing. Radiometric calibration determines the calibration in-flight of each detector, that is, the conversion from digital number to absolute radiance. The primary purpose of the L1R processing is to convert the brightness of the image pixels to absolute radiance. This process uses various ground- and in-flight-determined calibrations, i.e., Internal Calibrator, PASC, FASC, and night scenes. Additionally, the Radiometric Processing Subsystem characterizes the quality and various features of the data, .e.g., inoperable detectors, image artifacts etc.[3,4]

- The Geometric Processing Subsystem performs geometric calibration and L1G processing. This subsystem processes raw L0R or radiometrically corrected (L1R) imagery into geometrically corrected (L1G) imagery. Additionally, it characterizes the quality and various features of the data. The L1G image can be processed to three levels: systematic (L1Gs), precision-corrected (L1Gp), and precision/terrain-corrected (L1Gt).

  The IAS Geometric Processing Subsystem was best described by Jim Storey, USGS: "The overall purpose of the IAS geometric algorithms is to use Earth ellipsoid and terrain surface information in conjunction with spacecraft ephemeris and attitude data, and knowledge of the Enhanced Thematic Mapper Plus (ETM+) instrument and Landsat 7 satellite geometry to relate locations in ETM+ image space (band, scan, detector, sample) to geodetic object space (latitude, longitude, and height). These algorithms are used for purposes of creating accurate Level 1 output products, characterizing the ETM+ absolute and relative geometric accuracy, and deriving improved estimates of geometric calibration parameters such as the sensor to spacecraft alignment."[5]

- The Evaluation and Analysis Subsystem provides the tools required by the analyst to evaluate and analyze the performance of the ETM+ instrument, perform anomaly investigations, and maintain the CPF. Included are capabilities for viewing system input, processing reports and results (data analysis, statistical analysis and trending), and report generation. Additionally, the Evaluation and Analysis tools permit an analyst to invoke specific aspects of radiometric and geometric processing that perform characterization and calibration functions. The results of the analysis coupled with trending results are used to update the CPF. The Evaluation and Analysis capability also provides the analyst capabilities for editing system input and intermediate results and for submitting processing requests in support of "what if" analysis.

4.3 Concept of Operations

The IAS analyst orders up to 10 L0R products per day from the EDC DAAC for analysis and creates a work order, i.e., procedure for processing a L0R image to a L1 image, for each. The IAS software automatically ingests the L0R data and schedules it for processing according to the work order specifications. It assesses the L0R input data and processes it to L1R and L1G for assessment as L1 products. Image data are assessed with respect to their radiometric and geometric qualities both on an individual product basis and for long-term trend analyses.

The primary product of the IAS is the CPF. As part of this process the IAS submits special imaging requests to the MOC for partial aperture solar calibrator (PASC), full aperture solar calibrator (FASC), or calibration lamp cycling. The IAS analysts use the individual assessments of the L0Rs and the trending data to determine the updates to the CPF and generate reports concerning Landsat 7 instrument performance. These reports, along with an updated CPF when applicable, are provided to

the MOC and the ECS. Users, who order L0R products from the ECS, subsequently receive this CPF file as part of their order.

4.4 Management Aspects

The IAS project began late in 1994 and was reorganized in June 1996 thereby compressing the development phase. In February 1998 Release 2.0 was delivered to operations for acceptance testing. Release 3.0 following in June 1998 and it consisted of 223,000 DSI, which included header files, C source code, Oracle Forms and Menus, IDL, Unix Scripts, and SQL scripts. Between June 1998 and July 1999 one software release and eight patches were generated due to new requirements, data format changes, and software errors adding 1500 DSI to the total. The most significant challenges for the IAS development were the compressed software development schedule coupled with extremely complex scientific algorithms to implement and the lack of L0R scenes to test with. The compressed schedule necessitated tailoring the software development cycle by performing box level testing in lieu of unit testing. The lack of L0R scene data necessitated the development of a complex software testing tool that subsets, extracts, and generates Landsat 7 like Level 0R scenes from Landsat 5 data. The success of the IAS project is attributed to the following: frequent working group meetings (2-3 per week), maintaining strict CM procedures, box level testing in lieu of unit testing, peer software inspections, thorough on-site testing by operations personnel, and highly dedicated and motivated badgeless development teams.

5. OVERVIEW LEVEL 1 PRODUCTION SYSTEMS

The Level 1 production systems consist of two distinct systems: the Level 1 Product Generation System (LPGS) and the Level 1 Product Distribution System (LPDS). The LPGS is responsible for acquiring L0R data associated with the Level 1 orders, performing the requested radiometric and geometric processing, and generating the product in the user-specified format. The LPDS is responsible for receiving the L1 orders from the EDC Billing and Accounting system, prioritizing them for processing, staging the orders for the LPGS, submitting orders for the associated L0R data to the ECS, and generating and distributing the final L1 products.

5.1 Level 1 Product Generation System (LPGS)

The LPGS is a batch-oriented system driven by scripts that generate Landsat 7 Level 1 Products to the specifications provided by the customers. It interfaces with the LPDS and ECS for user product generation requests and data acquisition respectively. It can produce Level 1 products for a WRS scene or a floating subinterval sized between one half scene and three scenes. The LPGS is sized to sustain a daily volume of 100 WRS scene equivalent Level 1 products.

The major functions of the LPGS are summarized as follows:

1. Receive user product generation requests from the LPDS, signal LPDS when to order L0R data, and acquire the corresponding L0R data from the ECS to process the request
2. Generate 100 L1 WRS scene equivalent products per day in any combination of L1R or L1G products. Format L1R products in HDF. Format L1G products in FAST-L7A, HDF, or GeoTIFF
3. Compensate for inoperable and saturated detectors, and image artifacts of striping, banding, coherent noise, memory effect, scan correlated shift, and dropped scan lines
4. Produce geometric products that have been systematically corrected with the map projection, (oblique mercator, universal transverse mercator, lambert conformal conic, transverse mercator, oblique mercator, polyconic, and polar stereographic), resampling method (nearest neighbor, cubic convolution, or modulation transfer function), and orientation (north up or nominal path) selected by the user

5.1.1 Hardware Architecture

The operational LPGS hardware consists of one SGI Origin 2000 computer and two SGI O2 workstations, and an X-terminal. The Origin 2000 contains 16 R10K CPUs, 24 GB of RAM, and 1.1 TB of Ciprico RAID external disk drives. The X-terminal is used for the operator interface, and the O2 workstations are used for product analysis when necessary. The O2 workstations are equipped with 4 GB disk drives, 512 MB RAM, and monitors with a 1280x1024 resolution. A second SGI Origin 2000 is used for software maintenance and serves as a "cold-spare" to the operational system. It has eight processors, 12 GB of RAM, and 288 GB of external RAID disk drives.

5.1.2 Software Architecture

The LPGS software architecture incorporates custom C software, IAS software reuse, and several COTS products. The COTS products include the Oracle Database Management System, ENVI, and IDL. The LPGS reused IAS' Radiometric Processing and Geometric Processing Subsystems. Portions of the IAS Process Control and Data Management functions were also reused. The LPGS is similar architecture is similar to that of IAS. However, there are significant differences that reflect the minimal operator intervention criteria of LPGS, as well as the minimal analytical staff. All inter-process communication occurs via the Oracle database, script parameters, or Oracle pipes. The LPGS software consists of the following subsystems: Process Control, Data Management, Radiometric Processing, Geometric Processing, Quality Assessment, and Anomaly Analysis.

- Process Control Subsystem manages LPGS production planning and processing. It automatically takes product generation requests, i.e., specifications for customers order, and initiates monitors, and controls processing. Additionally, Process Control provides processing status in response to operator requests and manages LPGS resources for availability.

- Data Management Subsystem maintains and provides access to LPGS data stores. It handles communication protocols with the LPDS and ECS. Data Management ingests and formats files for use by its subsystems, providing cursory quality checks where needed to ensure the completeness of received and prepared products. It also provides formatting and packaging of L1 output and makes these data available to the LPDS.

- Radiometric Processing Subsystem is reused from the IAS. The LPGS does not utilize all of the radiometric algorithms because it does not collect calibration data, nor does LPGS process PASC or FASC data. LPGS Radiometric Processing provides the results of characterizations performed and the processing status for use by IAS and the Quality Assessment Subsystem.

- Geometric Processing Subsystem is reused from the IAS Geometric Processing Subsystem. It creates systematically corrected L1G imagery from L1R products. However, it does not perform terrain or precision correction, nor are calibration data produced.

- Quality Assessment Subsystem generates and assembles postproduction information about image artifacts and effects that were not corrected, and it produces a summary of the processed image quality. It performs automated quality assurance after radiometric and geometric corrections of images have been made. Additionally, the Quality Assessment software provides capability for visual inspection of images after radiometric correction, geometric correction, and final product formatting.

- Anomaly Analysis Subsystem analyzes L1 images and associated post production information to resolve image production anomalies. Typically the focus is on L0R products that could not be successfully processed to L1 or that failed visual inspection. Additionally, using baselined L0R products, Anomaly Analysis permits an analyst to perform benchmark tests to confirm the integrity and performance of the LPGS after any system upgrades.

5.1.3 Concept of Operations

The LPGS automatically produces L1 images as user requests are received from the LPDS. When resources are available the LPGS notifies the LPDS to post orders for L0R products in electronic format from the ECS. The LPDS receives notification of data availability and subsequently informs the LPGS for L0R data acquisition. The acquired L0R product is processed to L1 as specified by the user (e.g., Level 1G, GeoTIFF, space oblique mercator map projection, resampling method, etc.). During processing selected trending statistics are recorded for subsequent retrieval and processing by the IAS. LPDS retrieves the L1 product from the LPGS, copies it to appropriate media, validates it, and notifies the LPGS of completion for subsequent file deletion. The LPGS system may be configured for manual visual quality inspection if necessary.

5.1.4 Management Aspects

Development of the LPGS began in August 1996, and with delivery of Release 3.0, in January 1999, all requirements had been implemented. Several maintenance deliveries followed that reflected changes in LPGS requirements, identified errors,

and changes in data format. When LPGS became operational, it totaled close to 220,000 DSI which included header files, C code, Oracle Forms and Menus, IDL, UNIX scripts, and SQL scripts. Of the 220,000 DSI, almost 135,000 are attributable to re-use of IAS, including radiometric and geometric processing software.

The significant challenges for the development of the LPGS were the reuse of the IAS Radiometric and Geometric software subsystems and the late change in external interface requirements from ECS to LPDS. LPGS maximized the reuse of the IAS software but the LPGS' schedule was significantly behind the IAS, which made it very difficult to influence key requirements decisions. Often times circumstances did not permit reuse improvement changes to the IAS hence translation software was generated that reformatted user supplied processing parameters so that the radiometric and geometric subsystems could use it. Additionally, the LPDS was added in lieu of ECS in an effort to reduce the schedule for Level 1 product media generation and distribution to the launch plus 90 days time frame. The LPGS-ECS interface was replaced with the LPGS-LPDS interface necessitating a significant amount of software rework. In retrospect the success of the project can be attributed to highly dedicated professionals.

5.2 Level 1 Product Distribution System (LPDS)

The Level 1 Product Distribution System (LPDS) is the "middle man" of all Level 1 processing. It interfaces with the EDC billing and accounting system for receipt of approved data orders, the ECS for L0R data ordering, and the LPGS for L1 processing. It contains custom software for managing the data orders, utilizes the EDC-built Product Distribution System (PDS) for media generation, and has a stand along server / application called the DAAC L1 Server for the handling of L1 data searches, browse requests, and orders as the ECS only recognizes orders for L0R data. All Level 1 product generation is performed in an "on-demand" first-in-first-out basis, assuming resource availability. The LPDS was designed to sustain the production of the equivalent of 100 WRS scenes per day.

The major functions of the LPDS are summarized as follows:

- Facilitate the generation of Level 1 products and distribute them electronically or in 8-mm or CD-ROM
- Interface with the EDC billing and accounting system for receipt of L1 orders and status reporting
- Coordinate generation of Level 1 products with the LPGS
- Provide product status information to EDC User Services
- Bridge Landsat 7 Level 1 inventory searches and orders from the V0 IMS Client to the L0R based ECS

5.2.1 Hardware Architecture

The operational LPDS hardware consists of one SGI Origin 2000 computer, an SGI Origin 200 computer, a SGI O2 workstation, two Rimage CD-RW Super Producers, several X-terminals, two networked Genicom label printers, and a Tektronix Phaser 740 Color Laser Printer. The SGI Origin 2000 has four R10K CPUs, 768 MB RAM, and externally connected 216 GB of Ciprico RAID disks, six 8mm tape drives, and eight CD-R readers. The Origin 200 has one R10K CPU, 640 MB of RAM, and 288 GB of Ciprico RAID disks connected to it. The Rimage Super Producers consist of a Pentium II PC coupled to a CD picker with four CD-RWs. The Super Producers can load, burn, and label CDs automatically and can hold up to 50 CDs at a time. The Origin 2000 is the backbone of all processing and the Origin 200 server supports the electronic file distribution. The SGI O2 workstation serves as a system console for the Origin systems and the X-terminals support the operator interfaces. The Color Laser Printer is used to generate a full-color thumbnail image of the user's product on the CD-ROM cover. The system was designed to produce a maximum of 200 CD-ROMs, 50 8-mm tapes, or stages 50 electronic files for transfers per day such that any combination of the media counts does not exceed the equivalent of 100 WRS scene products per day.

5.2.2 Software Architecture

The LPDS software incorporates custom C programming language with embedded Oracle SQL and Forms and the existing EDC-built Product Distribution System (PDS). The LPDS subsystems are the Order Manager, Acquire Manager, Ingest Manager, Product Distribution System, the Operator Interface, and the DAAC L1 Server.

- The Order Manager Subsystem captures, validates, and acknowledges L1 orders sent from the billing and accounting system and queues the order information for retrieval by the LPGS

- The Acquire Manager Subsystem coordinates L0R data ordering between the LPGS and ECS such that ordering only occurs when the LPGS is ready for more data. Additionally, order identification keys from the ECS and the billing and accounting system are collated to ensure product traceability

- The Ingest Manager Subsystem coordinates between the LPGS and the PDS for the production of the final product

- The Product Distribution System Subsystem copies the Level 1 products to 8-mm tape, or CD-ROM or stages the data for electronic transfer to the user

- The Operator Interface Subsystem uses Oracle Forms to provide a menu-driven graphical user interface facilitating the management of all subsystems including order monitoring, promoting, resetting, and canceling

- DAAC L1 Server Subsystem hides the details of the handling of the Level 1 products from the L0 based ECS by intercepting and converting Level 1 directory and inventory searches, browse requests, and product orders to L0R directory and inventory searches, browse requests, and product orders. It also handles the conversion of L0R inventory searches to L1 directory and inventory search results and forwards the browse images.

5.2.3 Concept of Operations

Via the EOS V0 IMS[‡] web interface a customer searches and browses the Landsat archives at the EDC DAAC and submits an order for a Level 1 product. The order is sent to the EDC User Services for validation and approval. Upon approval the order is forwarded to the LPDS for processing via the billing and accounting system.

The LPDS autonomously waits for the EDC billing and accounting system to send orders. All orders received by the LPDS are stored in a Level 1 order queue and passed to the LPGS based on a first-in-first-out basis, subject to media quotas and operator override direction. The orders progress through several intermediate processing queues as the associated L0R data are ordered, acquired, processed by the LPGS, and processed by the PDS. The LPGS stages the Level 1 products on its disk drives until the PDS copies the files, generates the specified media, and verifies the media. The operator manually loads and unloads tapes and CD-ROMs as prompted by the PDS for product verification. Additionally the operator collates media, labels, and delivery letters. Finally, the billing and accounting system is notified of order completion.

5.2.4 Management Aspects

Development of the LPDS began January 1998 and a launch ready version was delivered in February 1999. Release 2.0B was delivered to operations July 1999, and the final release was delivered in August 1999. The LPDS was designed, developed, and tested over a period of 20 months. Approximately 35,000 DSI, not counting the PDS, were developed, adapted, or converted during that period. The most significant challenge for the development of the LPDS was the compressed schedule coupled with a large number of external interfaces. The success of the project is attributed to strict requirements control, simplification of interfaces, close collaboration with knowledgeable EDC DAAC development personnel, utilization of Landsat cognizant personnel, early software prototyping of key functions, and reusing the EDC-built PDS.

6. OVERVIEW - EDC DAAC ECS

The EDC provides one of eight DAACs of the Earth Observing System[6] (EOS) Data and Information System (EOSDIS). EOSDIS is one of the major elements of the EOS Program, a principal element of the Earth Science Enterprise (ESE). ESE is a long-term NASA research mission designed to improve our understanding of the Earth's interrelated processes involving the atmosphere, oceans, land surfaces, and polar regions[7]. EOSDIS is an end-to-end data system that include flight operations, data acquisition, data capture, initial processing, and backup archival. Data are routed to the DAACs and further processed into products for archival and distribution. Landat 7 only uses the DAAC portion of the EOSDIS for archival and distribution of data. Specifically, the data are held in the EOSDIS Core System (ECS).

[‡] See following URL for ordering L7 data http://harp.gsfc.nasa.gov/~imswww/pub/imswelcome/

The ECS performs the following functions for Landsat: long-term data archiving, scene subsetting, and WRS L0R scene distribution. It also supports data search, browse, and order capabilities and interfaces with the LPS, IAS, and Level 1 processing systems. The EDC DAAC holds the data for the Landsat 7, MODIS/Aster, Terra (AM-1), and Aqua missions.

The Landsat 7 related functions of the ECS are summarized as follows:

- Interface with the LPS for receipt and archive of L0R subintervals, browse images, and associated metadata
- Correlate Landsat Format 1 and Format 2 subintervals during data ingest process
- Interface with International Ground Stations for receipt of browse images and metadata
- Receive, archive, and distribute the Landsat 7 CPF from the IAS
- Report WRS scenes archived and associated cloud coverage score to GSFC MOC
- Interface with the EDC Billing and Accounting system
- Support customer search, browse, and order capabilities through EOSDIS Data Gateway
- Perform scene subsetting on a WRS boundary
- Ingest a maximum of 140 GB of data from the LPS and up to 110 distribute 110 L0R products per day to the Level 1 Processing systems or customers.

The ECS interfaces with the LPS for ingest of the processed Landsat 7 L0R subintervals, associated metadata, and browse images. A subset of the metadata and the browse images are aggregated into a database for search, browse, and order support. The EDC DAAC copies the data from the various LPS systems after notification of data availability is received. During the ingest and archive process the ECS must correlate the format 1 and format 2 subintervals because the data are received from independent computers within the LPS. When a scene is ordered the subinterval is recalled from off-line storage and staged for scene subsetting and subsequent L0R product generation, i.e., 8-mm tape or electronic transfer.

7. SUMMARY

The Landsat 7 Science Data Processing System went operational several days after spacecraft launch on April 15, 1999. The EDC DAAC began selling Landsat L0R and L1 products in the fall of 1999. In 24 hours the Science Data Processing System can capture and archive the equivalent of 275 WRS scenes and can distribute the equivalent of 100 WRS L0R or L1 scenes. The success of the Science Data Processing System is attributed to the dedicated professionals who developed and operate the systems. The systems are currently in operation at the EROS Data Center under the auspices of the USGS, Department of the Interior[8]. The LPS[†], IAS, and LPGS software are available as freeware via the following methods. The LPS and LPGS software is available upon request from the L7 Program Manager. Please direct your inquires to the L7 Program Manager, EROS Data Center, U.S.Geological Survey, 47914 252nd St. Sioux Falls, SD., 57198. The IAS software may be obtained on line via http://landsat7.usgs.gov/ under the Technical Information and IAS Software Registration popup menu items. A PC adapted version of the LPGS called LPGS-LITE is available via the Open Source Remote Sensing (OSRS) web server at http://www.remotesensing.org/. The COTS products used by these systems may be licensed from the applicable vendors.

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[†] Note: The LPS VME-9U-VSIO device driver is not available as freeware.